Realtime dose monitoring technologies: Luxury or Necessity

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About me

• Disclaimer
  – Founder and President of Crux Quality Solutions LLC (CruxQS) providing software, hardware and consulting solutions in radiation oncology
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  – Director of Medical Physics at Baylor Scott and White Health, Temple, Texas
  – Associate Professor at Texas A&M University, Temple, Texas
  – Chief of Quality Assurance at Washington University Saint Louis, Missouri

• Education
  – University of Missouri Columbia – MS & PhD in Nuclear Engineering
  – Indian University Purdue University – Postdoctoral in Medical Physics( MLC tracking of Lung tumors)
  – Washington University Saint Louis – Residency in Radiation Oncology Physics

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  – 317-652-6059
• Radiation eye View:
  – Cancer is not a problem but normal tissues are ???
  – Technology development and research has been done with one common goal

To increase the dose to tumor and reduce to normal tissues safely, accurately and with efficacy.
To achieve the goal of radiation therapy continuous innovation is needed in 3 primary focus areas

– Delivery technology (Treatment Machines like Linac)
– Targeting technology (Imaging)
– Delivery QA technology
X-ray Treatment Delivery Technology Evolution

• 1900s  Radium needles
• 1925  50kv Superficial X rays
• 1948  Co-60
• 1953  Linac
• 1990  MLC – 2D to 3D
• 1996  IMRT
• 2000s  Arc therapy
• 2000s  Stereotactic Radiotherapy

Image Guided Radiation Therapy Evolution

• Visual inspection
• Visual Inspection and marking
• Light Field projection and marking
• 1970s 2D projections KV Port Films
• 2000s CBCT
• 2000s Real time Orthogonal x-rays for moving targets

Dose Escalation Evolution (eg. Prostate)

• 40 Gy
• 50 Gy
• 60 Gy
• 76 Gy
• 80 Gy
• 90 Gy - Protons
• 100 Gy - Carbon

Real time Dose Monitoring Evolution

• Timer
• Timer
• Timer (Co-60)
• MU Ion Chamber (Linac)
• Delivery technology out paced QA technology
• It is difficult to build realtime dose monitoring
• Common practice trump common sense
• Assumptions vs Assurance vs Ambiguity
Common sense approach

• **Measure** errors separately and then combine the effect to be Precise and Accurate

• **Automate**

  Efficient and Consistent
Other Approach

• Combine everything and then measure – Exit dosimetry
• Derive the error measuring surrogate - Log file or R&V records
• Transmission Detectors
Scientific Argument

- Errors in Delivery
  - Machine output
  - Fluctuations in beam characteristics
  - MLC errors
  - Patient Set up errors
  - Others
Evaluation of the efficiency and effectiveness of independent dose calculation followed by machine log file analysis against conventional measurement based IMRT QA

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Sridhar Yaddanapudi,1 Omar Wooten,1 Sasa Mutic1

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Received 7 December, 2011; accepted 30 May, 2012
Effectiveness in catching errors

<table>
<thead>
<tr>
<th>Data Transfer, Delivery Error, Planning Error Type</th>
<th>Point Dose Measurement</th>
<th>Field-by-Field Planar Dose QA*</th>
<th>Composite Planar Dose QA*</th>
<th>DataLog QA*</th>
<th>Independent Dose Calculation QA*</th>
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<tbody>
<tr>
<td>Beam Parameters Discrepancy During Data Transfer or Machine Delivery</td>
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<tr>
<td>Gantry Angle</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>5</td>
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<tr>
<td>Collimator Jaw Setting</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Collimator Angle</td>
<td>3</td>
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<td>3</td>
<td>1</td>
<td>5</td>
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<td>MLC Positioning Error</td>
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<td>4</td>
<td>3</td>
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<td>MUs</td>
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<td>1</td>
<td>1</td>
<td>3</td>
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<td>Couch Angle Error</td>
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<td>5</td>
<td>2</td>
<td>5</td>
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<tr>
<td>Machine Issues/Data Transfer Issues</td>
<td></td>
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<tr>
<td>Dosimetry Characteristics – Energy Change, Symmetry and Flatness Off</td>
<td>4</td>
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<td>5</td>
<td>5</td>
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<td>Absolute Dose Output Calibration</td>
<td>5</td>
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<td>Relative Dose Output – Small Field Output Off</td>
<td>1</td>
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<td>1</td>
<td>5</td>
<td>5</td>
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<tr>
<td>One Segment Dropped Out or Not Transferred Properly</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>5</td>
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<tr>
<td>One Field Not Transferred Correctly</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>5</td>
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<tr>
<td>Dosemation MLC Sequence or MLC Positioning Issues – Beam Hold Off</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>5</td>
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<tr>
<td>TPS Beam Modeling Issues</td>
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<tr>
<td>Small Field Out Prediction Issue</td>
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<td>2</td>
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<td>1</td>
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<td>Heterogeneity Correction Issues</td>
<td>5</td>
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<td>Wrong CT to ED</td>
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<td>5</td>
<td>5</td>
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<td>DVH Calculation Discrepancy</td>
<td>5</td>
<td>3</td>
<td>5</td>
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<tr>
<td>In vivo Changes</td>
<td></td>
<td></td>
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<tr>
<td>Beam Data Modification After Procurement QA and Other Machine Issues During Each Fraction</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>IGRT Issues</td>
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<tr>
<td>Anatomy Changes, localization Issues, Setup Issues</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Treatment Planning</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect Placement, Prescription, Wrong CT Voxel Size, Plan Quality</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

You can see there is not do it all tool.
Catching errors with patient-specific pretreatment machine log file analysis

Dharanipathy Rangaraj PhD*, Mingyao Zhu PhD, Deshan Yang PhD, Geethpriya Palaniswaamy PhD, Sridhar Yaddanapudi MS, Omar H. Wooten PhD, Scott Brame PhD, Sasa Mutic PhD

Department of Radiation Oncology, Washington University School of Medicine, St Louis, Missouri
Table 1  Distribution of the 912 machine log file quality assurance by treatment sites, and the list of errors detected grouped by treatment site and error type

<table>
<thead>
<tr>
<th>Distribution</th>
<th>No. of patients</th>
<th>No. of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>By treatment site</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head and neck</td>
<td>216</td>
<td>3</td>
</tr>
<tr>
<td>Prostate</td>
<td>188</td>
<td>1</td>
</tr>
<tr>
<td>Brain</td>
<td>127</td>
<td>1</td>
</tr>
<tr>
<td>Pelvis</td>
<td>78</td>
<td>2</td>
</tr>
<tr>
<td>Lung</td>
<td>74</td>
<td>0</td>
</tr>
<tr>
<td>Rectum</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>Breast</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>151</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>912</td>
<td>14</td>
</tr>
<tr>
<td>By error type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human operating error</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Flawed plan</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Data transfer problem</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

*a* Error: Any unintended deviation (beyond the set tolerance) from the planned treatment beam parameters identified from the delivery log (Dynalog) files analysis.

Table 2  Statistics of the 174 Dynalog quality assurance reports with false positives, unreliable results, and minor errors

<table>
<thead>
<tr>
<th>Warning message type</th>
<th>No.</th>
<th>SMLC</th>
<th>DMLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low pass rate of fluence map</td>
<td>123</td>
<td>83</td>
<td>40</td>
</tr>
<tr>
<td>Carriage A and B</td>
<td>11</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>No. of beams more than plan</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>No. of beams less than plan</td>
<td>16</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Collimator angle</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Minor MLC position error without considering beam hold off</td>
<td>36</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>MLC position error with considering beam hold off</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other unreliable results</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>174</td>
<td>123</td>
<td>51</td>
</tr>
</tbody>
</table>

DMLC, dynamic multileaf collimator; MLC, multileaf collimator; SLMC, static multileaf collimator.
Catching errors with *in vivo* EPID dosimetry

A. Mans, a) M. Wendling, b) L. N. McDermott, c) J.-J. Sonke, R. Tielenburg, R. Vijlbrief, B. Mijnheer, M. van Herk, and J. C. Stroom

*Department of Radiation Oncology, The Netherlands Cancer Institute—Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands*

(Received 9 July 2009; revised 5 March 2010; accepted for publication 29 March 2010; published 18 May 2010)

The potential for detrimental incidents and the ever increasing complexity of patient treatments emphasize the need for accurate dosimetric verification in radiotherapy. For this reason, all curative treatments are verified, either pretreatment or *in vivo*, by electronic portal imaging device (EPID) dosimetry in the Radiation Oncology Department of the Netherlands Cancer Institute-Antoni van Leeuwenhoek hospital, Amsterdam, The Netherlands. Since the clinical introduction of the method in January 2005 until August 2009, treatment plans of 4337 patients have been verified. Among these plans, 17 serious errors were detected that led to intervention. Due to their origin, nine of these errors would not have been detected with pretreatment verification. The method is illustrated in detail by the case of a plan transfer error detected in a 5×5 Gy intensity-modulated radiotherapy (IMRT) rectum treatment. The EPID reconstructed dose at the isocenter was 6.3% below the planned value. Investigation of the plan transfer chain revealed that due to a network transfer error, the plan was corrupted. 3D analysis of the acquired EPID data revealed serious underdosage of the planning target volume: On average 11.6%, locally up to 20%. This report shows the importance of *in vivo* (EPID) dosimetry for all treatment plans as well as the ability of the method to assess the dosimetric impact of deviations found. © 2010 American Association of Physicists in Medicine. [DOI: 10.1118/1.3397807]
## Table I. Errors detected by means of EPID dosimetry from the clinical introduction to July 2009, grouped by (a) treatment site and (b) error type.

<table>
<thead>
<tr>
<th>(a) Site</th>
<th>Clinical introduction</th>
<th>No. of patients</th>
<th>No. of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prostate</td>
<td>02–2005</td>
<td>1018</td>
<td>2</td>
</tr>
<tr>
<td>Rectum</td>
<td>07–2006</td>
<td>602</td>
<td>4</td>
</tr>
<tr>
<td>Head-and-neck</td>
<td>06–2007</td>
<td>543</td>
<td>4</td>
</tr>
<tr>
<td>Breast</td>
<td>01–2008</td>
<td>1319</td>
<td>2</td>
</tr>
<tr>
<td>Lung</td>
<td>01–2008</td>
<td>454</td>
<td>2</td>
</tr>
<tr>
<td>Others</td>
<td>01–2008</td>
<td>401</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>4337</strong></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) Error type</th>
<th>No. of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient anatomy</td>
<td>7</td>
</tr>
<tr>
<td>Plan transfer</td>
<td>4</td>
</tr>
<tr>
<td>Suboptimally tuned TPS parameter</td>
<td>2</td>
</tr>
<tr>
<td>Accidental plan modification</td>
<td>2</td>
</tr>
<tr>
<td>Failed delivery</td>
<td>1</td>
</tr>
<tr>
<td>Dosimetrically undeliverable plan</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>

![Fig. 2. \(\gamma\)-evaluations of (a) the first (malformed plan) and (b) the second (corrected plan) fractions in a plane parallel to the EPID, intersecting the isocenter. The white “+” indicates the isocenter.](image-url)
A clinically observed discrepancy between image-based and log-based MLC positions

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Department of Radiation Oncology, University of Virginia, Charlottesville, Virginia 22908

(Received 22 February 2016; revised 22 April 2016; accepted for publication 28 April 2016; published 17 May 2016)

Purpose: To present a clinical case in which real-time intratreatment imaging identified an multileaf collimator (MLC) leaf to be consistently deviating from its programmed and logged position by >1 mm.

Methods: An EPID-based exit-fluence dosimetry system designed to prevent gross delivery errors was used to capture cine during treatment images. The author serendipitously visually identified a suspected MLC leaf displacement that was not otherwise detected. The leaf position as recorded on the EPID images was measured and log-files were analyzed for the treatment in question, the prior day’s treatment, and for daily MLC test patterns acquired on those treatment days. Additional standard test patterns were used to quantify the leaf position.

Results: Whereas the log-file reported no difference between planned and recorded positions, image-based measurements showed the leaf to be 1.3±0.1 mm medial from the planned position. This offset was confirmed with the test pattern irradiations.

Conclusions: It has been clinically observed that log-file derived leaf positions can differ from their actual position by >1 mm, and therefore cannot be considered to be the actual leaf positions. This cautions the use of log-based methods for MLC or patient quality assurance without independent confirmation of log integrity. Frequent verification of MLC positions through independent means is a necessary precondition to trust log-file records. Intratreatment EPID imaging provides a method to capture departures from MLC planned positions. © 2016 American Association of Physicists in Medicine. [http://dx.doi.org/10.1118/1.4949002]
MLC actual vs predicted

Fig. 1. Real-time patient treatment images from consecutive days. The image on the right shows an MLC leaf displaced with respect to the neighboring leaves, and with respect to the image on the left from the previous day. This leaf offset was persistent throughout the beam delivery.
A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy

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(Received 16 March 2015; revised 8 June 2015; accepted for publication 3 August 2015; published 19 August 2015)

Purpose: Complex treatments in radiation therapy require robust verification in order to prevent errors that can adversely affect the patient. For this purpose, the authors estimate the effectiveness of detecting errors with a “defense in depth” system composed of electronic portal imaging device (EPID) based dosimetry and a software-based system composed of rules-based and Bayesian network verifications.

Methods: The authors analyzed incidents with a high potential severity score, scored as a 3 or 4 on a 4 point scale, recorded in an in-house voluntary incident reporting system, collected from February 2012 to August 2014. The incidents were categorized into different failure modes. The detectability, defined as the number of incidents that are detectable divided total number of incidents, was calculated for each failure mode.

Results: In total, 343 incidents were used in this study. Of the incidents 67% were related to photon external beam therapy (EBRT). The majority of the EBRT incidents were related to patient positioning and only a small number of these could be detected by EPID dosimetry when performed prior to treatment (6%). A large fraction could be detected by in vivo dosimetry performed during the first fraction (74%). Rules-based and Bayesian network verifications were found to be complimentary to EPID dosimetry, able to detect errors related to patient prescriptions and documentation, and errors unrelated to photon EBRT. Combining all of the verification steps together, 91% of all EBRT incidents could be detected.

Conclusions: This study shows that the defense in depth system is potentially able to detect a large majority of incidents. The most effective EPID-based dosimetry verification is in vivo measurements during the first fraction and is complemented by rules-based and Bayesian network plan checking.

© 2015 American Association of Physicists in Medicine. [http://dx.doi.org/10.1118/1.4928601]
Figure 3 shows the detectability of failure modes by \textit{in vivo} all fraction EPID dosimetry. This shows the added benefit over only making an \textit{in vivo} first fraction EPID dosimetry measurement. The failure modes with the largest benefit are movement on the table (F), treatment machine error (D), and setup errors. Errors such as wrong isocenter information and errors in the CT data will be detected in the first fraction and do not benefit from all fraction EPID dosimetry.

**Fig. 3.** \textit{In vivo} all fraction EPID dosimetry detectability vs occurrence.

The legend used for all figures is:
- A: wrong or faulty equipment used
- B: record & verify system down
- C: personnel could not be contacted
- D: treatment machine error
- E: scheduling error
- F: movement on table
- G: error in field planning
• Radiation errors are rare but when happen can be catastrophic
• Safety in radiation oncology is nowhere as reliable as aviation and nuclear industry or in medicine like anesthesia
• To become high reliable organization and make treatment safe to our patients tools such as these are needed
Moral Argument
Linear accelerators are programmed to send precise doses of radiation to cancerous tissues. They are used in a cancer fighting therapy called Intensity Modulated Radiation Therapy (I.M.R.T.).
Generating the beam

The machine produces a stream of electrons that is accelerated, guided and bent downward into a block of tungsten that converts the electrons into high-energy X-rays.
Guided by the computer-run treatment plan, a large gantry rotates around the patient, delivering radiation to cancerous tissues from different angles.
When all the leaves are closed, radiation is blocked.
If the collimator is mistakenly left open, the patient can be dangerously overirradiated.

The Fatal Error: March 14
Mr. Jerome-Parks’s early treatments had gone well, but multiple computer crashes occurred while the medical physicist tried to save a reformulated treatment plan. The instructions for the multileaf collimator were lost and the collimator leaves were fully open for three doses of radiation.
March 16, 2005
Mr. Jerome-Parks’s medical physicist ran a series of tests on the equipment. All of them showed that the collimator was wide open, and the hospital realized that a serious overdose of radiation had been administered.

February 2007
After two years of declining health, including loss of sight, hearing and balance, Mr. Jerome-Parks, 43, died of his radiation injuries.
These are no one off incidents

These are happening in very highly reputable cancer hospitals with mature protocols.

But on the day of the warning, at the State University of New York Downstate Medical Center in Brooklyn, a 32-year-old breast cancer patient named Alexandra Jn-Charles absorbed the first of 27 days of radiation overdoses, each three times the prescribed amount. A linear accelerator with a missing filter would burn a hole in her chest, leaving a gaping wound so painful that this mother of two young children considered suicide.

Ms. Jn-Charles and Mr. Jerome-Parks died a month apart. Both experienced the wonders and the brutality of radiation. It helped diagnose and treat their disease. It also inflicted unspeakable pain.

http://www.nytimes.com/2010/01/24/health/24radiation.html...
Errors are not things of the past

Dec 13th 2016

Patients sue St. Cloud cancer center, alleging negligent radiation therapy

At least a dozen people allege they suffered injuries because of radiation errors at Coborn in St. Cloud.

By David Chanen Star Tribune | DECEMBER 13, 2016 — 8:39PM

Sandy Schwegman is one of seven former patients at Coborn Cancer Center in St. Cloud to file lawsuits for botched therapy plans. The move pained Schwegman, who spent a career as a hospital nurse.
Safety in Radiation Therapy
Over the last three decades, at least 3000 patients affected by radiotherapy incidents. Medical Radiation accidents have accounted for more acute radiation deaths than any other source.
Dr. John J. Feldmeier, a radiation oncologist at the University of Toledo and a leading authority on the treatment of radiation injuries, estimates that 1 in 20 patients will suffer injuries.

“My suspicion is that maybe half of the accidents we don’t know about,” said Dr. Fred A. Mettler Jr., who has investigated radiation accidents around the world and has written books on medical radiation.

Identifying radiation injuries can be difficult. Organ damage and radiation-induced cancer might not surface for years or decades, while underdosing is difficult to detect because there is no injury. For these reasons, radiation mishaps seldom result in lawsuits, a barometer of potential problems within an industry.
There is no guarantee this will not happen in any clinic
ROI Argument

• Gain – Revenue or time
• Risk – Reduce liability
Why good choice assumption is not good enough or potentially unsafe
Medical Lawsuit

Caveats in Radiation therapy

a) Identifying radiation injury is difficult. Organ damage can take long time to be detected and under dosage is difficult to detect as there is no injury.
b) Medical errors are not adequately reported.
c) Because of difficulty in identifying medical errors, most mistake doesn’t result in lawsuits. The reported medical malpractice claims are not elaborately studied.
According to a study in International Journal of Radiation Oncology, Biology and Physics, the total cost of the paid malpractice claims between 1985 and 2012 is USD 129,954,578[1].
• According to a study in International Journal of Radiation Oncology, Biology and Physics, the total cost of the paid malpractice claims between 1985 and 2012 is USD 129,954,578[1].

Table 1: Malpractice claims in 1985-2012 in Radiation Oncology [1]

<table>
<thead>
<tr>
<th>Year</th>
<th>Closed Claims</th>
<th>Paid Claims</th>
<th>% Paid of Closed Claims</th>
<th>Total Expenses Paid</th>
<th>Average Expenses/Paid Claim</th>
<th>Total Expenses - Paid Claims</th>
<th>Average Expenses - Paid Claims</th>
<th>Total Expenses - No Indemnity</th>
<th>Average Expenses - No Indemnity</th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
<tr>
<td>Cumulative</td>
<td>1,517</td>
<td>342</td>
<td>22.5%</td>
<td>$129,954,578</td>
<td>$379,984</td>
<td>$25,585,100</td>
<td>$28,072</td>
<td>$19,031,669</td>
<td>$35,707</td>
</tr>
</tbody>
</table>

* Closed claims are medical liability claims that have been resolved through settlement or verdict or withdrawn, dropped or dismissed without payment.

† Paid claims are medical liability claims that resulted in indemnity payments to the plaintiff as a result of settlement or court adjudication.

‡‡ Adjusted for inflation, 2012 Index year.

§§ Expenses are litigation expenses related to the defense of a liability claim, including expenses paid in the process of administering or adjudicating a claim.

According to a study in International Journal of Radiation Oncology, Biology and Physics, the total cost of the paid malpractice claims between 1985 and 2012 is USD 129,954,578[1].

### Table 2: Closed Claims and indemnity payments by medical specialty, 1985-2012 [1]

<table>
<thead>
<tr>
<th>Medical Specialty</th>
<th>Closed Claims</th>
<th>Paid Claims</th>
<th>% Paid of Closed Claims</th>
<th>Total Indemnity Payment</th>
<th>Average Indemnity Payment</th>
<th>Median Indemnity Payment</th>
<th>Largest Indemnity Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anesthesiology</td>
<td>11,030</td>
<td>3,470</td>
<td>31.5%</td>
<td>$856,516,675</td>
<td>$296,683</td>
<td>$96,773</td>
<td>$5,048,078</td>
</tr>
<tr>
<td>Cardiology</td>
<td>5,371</td>
<td>1,032</td>
<td>19.2%</td>
<td>$271,207,784</td>
<td>$206,798</td>
<td>$156,250</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Cardiothoracic Surgery</td>
<td>7,948</td>
<td>1,900</td>
<td>23.9%</td>
<td>$452,058,679</td>
<td>$246,557</td>
<td>$125,000</td>
<td>$5,005,000</td>
</tr>
<tr>
<td>Dermatology</td>
<td>3,198</td>
<td>906</td>
<td>28.3%</td>
<td>$130,900,558</td>
<td>$114,482</td>
<td>$35,000</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Emergency Medicine</td>
<td>6,887</td>
<td>1,864</td>
<td>27.1%</td>
<td>$464,440,109</td>
<td>$247,554</td>
<td>$120,000</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Gastroenterology</td>
<td>3,521</td>
<td>661</td>
<td>18.8%</td>
<td>$170,353,285</td>
<td>$253,721</td>
<td>$119,559</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>General and Family Practice</td>
<td>30,453</td>
<td>9,639</td>
<td>31.7%</td>
<td>$1,703,213,764</td>
<td>$176,700</td>
<td>$82,246</td>
<td>$7,239,248</td>
</tr>
<tr>
<td>General Surgery</td>
<td>29,070</td>
<td>9,822</td>
<td>33.4%</td>
<td>$1,978,471,204</td>
<td>$201,433</td>
<td>$99,999</td>
<td>$3,166,110</td>
</tr>
<tr>
<td>Internal Medicine</td>
<td>37,216</td>
<td>9,271</td>
<td>24.9%</td>
<td>$2,106,112,462</td>
<td>$227,172</td>
<td>$104,400</td>
<td>$12,000,000</td>
</tr>
<tr>
<td>Neurology</td>
<td>4,474</td>
<td>979</td>
<td>21.9%</td>
<td>$326,529,544</td>
<td>$333,514</td>
<td>$175,000</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>6,440</td>
<td>1,814</td>
<td>28.2%</td>
<td>$599,480,751</td>
<td>$336,476</td>
<td>$183,735</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>Obstetrics and Gynecology</td>
<td>40,246</td>
<td>13,761</td>
<td>34.2%</td>
<td>$5,959,561,785</td>
<td>$246,624</td>
<td>$140,250</td>
<td>$13,000,000</td>
</tr>
<tr>
<td>Ophthalmology</td>
<td>7,893</td>
<td>2,232</td>
<td>28.3%</td>
<td>$429,070,088</td>
<td>$192,297</td>
<td>$180,000</td>
<td>$3,550,000</td>
</tr>
<tr>
<td>Orthopedic Surgery</td>
<td>25,708</td>
<td>7,404</td>
<td>28.8%</td>
<td>$1,329,643,166</td>
<td>$175,584</td>
<td>$90,000</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Otorhinolaryngology</td>
<td>4,627</td>
<td>1,529</td>
<td>33.1%</td>
<td>$336,006,438</td>
<td>$349,756</td>
<td>$100,000</td>
<td>$4,999,329</td>
</tr>
<tr>
<td>Pathology</td>
<td>1,991</td>
<td>594</td>
<td>29.8%</td>
<td>$158,426,561</td>
<td>$206,711</td>
<td>$157,500</td>
<td>$2,700,000</td>
</tr>
<tr>
<td>Pediatrics</td>
<td>7,625</td>
<td>2,180</td>
<td>27.9%</td>
<td>$618,020,900</td>
<td>$283,496</td>
<td>$125,251</td>
<td>$5,250,000</td>
</tr>
<tr>
<td>Plastic Surgery</td>
<td>10,174</td>
<td>2,697</td>
<td>26.5%</td>
<td>$333,545,019</td>
<td>$123,673</td>
<td>$50,000</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Psychiatry</td>
<td>2,666</td>
<td>526</td>
<td>19.7%</td>
<td>$81,278,265</td>
<td>$156,225</td>
<td>$155,000</td>
<td>$2,375,000</td>
</tr>
<tr>
<td>Radiation Oncology</td>
<td>1,517</td>
<td>342</td>
<td>22.5%</td>
<td>$91,662,971</td>
<td>$276,792</td>
<td>$122,500</td>
<td>$2,700,000</td>
</tr>
<tr>
<td>Radiology</td>
<td>16,411</td>
<td>4,740</td>
<td>28.9%</td>
<td>$1,088,473,088</td>
<td>$229,636</td>
<td>$108,000</td>
<td>$3,364,156</td>
</tr>
<tr>
<td>Urologic Surgery</td>
<td>7,999</td>
<td>2,009</td>
<td>28.3%</td>
<td>$404,586,596</td>
<td>$304,398</td>
<td>$100,000</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>All specialties</td>
<td>272,117</td>
<td>79,372</td>
<td>29.2%</td>
<td>$117,895,699,524</td>
<td>$225,221</td>
<td>$180,000</td>
<td>$13,000,000</td>
</tr>
</tbody>
</table>


2. Paid Claims are medical liability claims that resulted in indemnity payment to the plaintiff as a result of settlement or court adjudication.
We need to be our own Barometer?
• Workflow gain
  – Cash flow
• Marketing gain
  – Revenue (1 prostate IMRT patient a quarter can pay of it)
• Intangible
  – Protection against claims
  – Patient experience
  – Therapist Experience
Delta4 Discover Transmission Detector at UMC

- University Medical Center, Texas Tech University – First Clinical Discover System
  - Two Varian TrueBeam (one is Edge HD MLC)
  - Aria- Eclipse Environment
- Installation took 1 Days (including testing, ADI interface and software installation)
- Currently Commissioning for go live
- Going Live on April 17th 2018

First FDA approved Device
Diode-based transmission detector for IMRT delivery monitoring: a validation study

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The purpose of this work was to evaluate the potential of a new transmission detector for real-time quality assurance of dynamic-MLC-based radiotherapy. The accuracy of detecting dose variation and static/dynamic MLC position deviations was measured, as well as the impact of the device on the radiation field (surface dose, transmission). Measured dose variations agreed with the known variations within 0.3%. The measurement of static and dynamic MLC position deviations matched the known deviations with high accuracy (0.7–1.2 mm). The absorption of the device was minimal (~ 1%). The increased surface dose was small (1%–9%) but, when added to existing collimator scatter effects could become significant at large field sizes (≥ 30 × 30 cm²). Overall the accuracy and speed of the device show good potential for real-time quality assurance.
**Design**

- **4040** p-type diode
- Each Diode Active area of **1mm** diameter
- **25x20 cm** Projected at isocenter 100 SAD
- **MLC**
  - Travel Direction: 1.6 mm apart (**2.5mm @ iso**)  
  - Other direction: 3.2 mm apart (**5 mm @ iso**)  
- **Other**  
  - Overall Source to Device Distance is **63.6 cm** for Varian machine
- The device is charge by 4 batteries up to 4 hours each  
- Wirelessly communicate with the software  
- Slides in and out for light field  
- ODI is visible in both position (in and out)  
- Could be mounted and unmounted in **< 1 min** (10kg)
How it works

– Delta4 PT and Discover work together
– Dosimetric correlation are established between Delta4 PT and Discover
– Delta4 Discover Monitors Leaf position and errors
– Transmit every 25ms WiFi
– Then Dosimetry errors are calculated by dose perturbation using the model established during pretreatment
– Discover can also used independently to QA leaf positions during treatment
A. Impact on beam quality

Dose profiles (percentage depth dose, in-plane, and cross-plane) were virtually indistinguishable between measurements with and without the TRD in the beam path. The largest changes overall were a 0.5% decrease in the dose at 10 cm depth (median 0.0%), a 1.2 mm shift in the depth of maximum dose towards the surface (median 0.2 mm), a 0.3% decrease in flatness at 10 cm depth (median 0.0%), and a 0.5% increase in symmetry at a depth of dmax (median 0.05%).

The average transmission factor, due to the presence of the 2D transmission detector array, was $0.989 \pm 0.0015$ for 6 MV and $0.993 \pm 0.0006$ for 15 MV (one standard deviation (SD)). Figure 5 shows the surface dose increase for a range of beam energies and field sizes. The data points correspond to depth in water of approximately 0.6 mm. For field sizes less than $10 \times 10$ cm$^2$, the increase attributable to the detector is less than 1%. For the $40 \times 40$ cm$^2$ field size, an additional 8% (6 MV) and 9% (15 MV) surface dose was attributed to the addition of the TRD detector array. Table 1 provides a comparison of the transmission/surface dose increases due to this TRD (Delta$^4$) to other published TRDs.

![Graph showing surface dose with and without the presence of the TRD detector array.](image)
B.1 Output deviation

Figure 6 shows the detector’s response to linear accelerator output deviation simulated by manually delivering 1%–5% more MU. The measured signal at the detector was then compared to the original measurement. The MU linearity (measured during annual QA) was within 0.1% of the nominal MU, therefore the increase in MU can accurately simulate the machine output drift. The detector’s average response agreed with the actual output increase within 0.3%.

![Graph showing output deviation comparison](image)

**Fig. 6.** Comparison of measured and delivered beam output with 1%–5% manually introduced deviation. Error bars were the standard deviation of multiple measurement points.
Static MLC Error Simulation

Fig. 7. 1D profile of TRD measurement along one leaf. Different lines represent multiple manually introduced static MLC leaf position deviations from 1 mm to 5 mm. The legend provides a comparison between delivered shift and detected shift based on the location of 50% signal strength.
Fig. 8. Detected vs. introduced MLC position errors during a dynamic IMRT delivery. Results for a representative leaf pair #31 near the center of the field are shown. Error bars show the standard deviation across all measurement time points during the beam delivery.
We have evaluated a new 2D diode-based transmission detector, with 2.5 mm resolution over the central 25 cm × 20 cm area of the treatment field. This detector array has a small effect on the beam transmission/surface dose and successfully detected and quantified machine output deviations and MLC position offsets as low as 1% and 1 mm. The transmission diode array’s detection accuracy and precision for MLC positioning errors with both static and dynamic delivery are within 0.7 mm and 1.2 mm, respectively. Overall this 2D transmission detector array is a suitable candidate for online delivery monitoring.
Realtime Dose Monitoring Technologies

• Transmission Detectors has a key role in the Patient specific QA
• Put the patient back in the patient specific QA process
• Much more effective in detecting online dose errors (if done right)
• It is here to stay because
  – it is possible now and
  – it makes lot of sense
• UMC Lubbock we will be actively looking for any quality error or safety errors detected through this system
Acknowledgments

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• Ryan Schurr MS
• Ramzi Abdulrahman MD
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ScandiDos Team
• Greg Biggs
• Courtney Bateman PhD